(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 225 592 A2

D7

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 86116778.1

(22) Date of filing: 03.12.86

(51) Int. Cl.⁴: H01L 21/20, H01L 21/268, H01L 21/90

(30) Priority: 04.12.85 JP 272677/85

(43) Date of publication of application: 16.06.87 Bulletin 87/25

(84) Designated Contracting States: DE FR GB

(71) Applicant: FUJITSU LIMITED
1015, Kamikodanaka Nakahara-ku
Kawasaki-shi Kanagawa 211(JP)

(72) Inventor: Mukai, Ryoichi Fujitsu Ltd. Kosugi Fujitsu Bld.
1812-10 Shimonumabe
Nakahara-ku Kawasaki-shi Kanagawa 211(JP)

(74) Representative: Sunderland, James Harry et al
HASELTINE LAKE & CO Hazlitt House 28
Southampton Buildings Chancery Lane
London WC2A 1AT(GB)

(54) Recrystallizing conductive films.

- Rekristallisering van halfgeleidermateriaal

(57) A method of recrystallizing a region (3) of a nonmonocrystalline conductive layer (2), comprising:-
forming a thermal-conduction-controlling layer (5) above the nonmonocrystalline layer (the latter being, for example, of polysilicon or amorphous aluminum), the thermal-conduction-controlling layer having a portion (4) of increased thickness above and corresponding to the said region of the nonmonocrystalline conductive layer, so as to provide greater thermal resistance at that portion that is provided by surrounding portions;
forming an energy-absorbing cap layer (6) above the thermal-conduction-controlling layer; and
irradiating the energy absorbing cap layer with an energy beam (7);
the energy-absorbing cap layer absorbing energy from the beam and, as a result, heating up, the thermal-conduction-controlling layer conducting heat from the cap layer to the nonmonocrystalline layer in a selective fashion owing to the presence of the increased-thickness portion, such that material of the nonmonocrystalline layer in the said region is melted and provided with a temperature distribution such that it recrystallizes, on cooling, in a grain-boundary-free condition

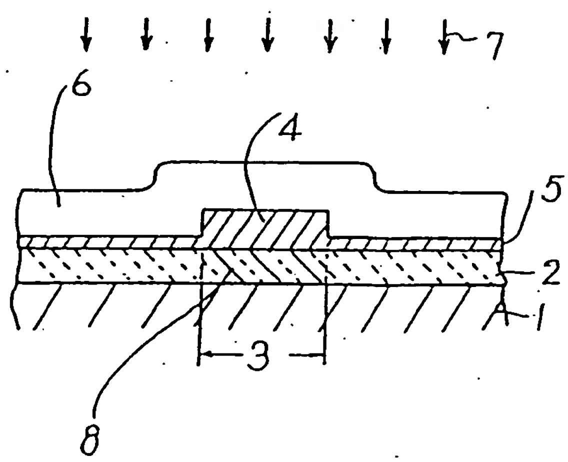

FIG. 2

EP 0 225 592 A2

Recrystallizing Conductive Films

The present invention relates to the recrystallization of conductive material films, including semiconductor films. The present invention finds application in SOI (Silicon on Insulator) technology.

SOI technology has been proposed as a means for providing high-speed and high-voltage semiconductor integrated circuits (ICs) and at present appears to be one of the most promising prospects for the realization of three-dimensional semiconductor integrated circuits.

In SOI technology, a polysilicon film, usually formed on an insulating layer such as a thermally-oxidized layer of a silicon substrate, is recrystallized, so as to end up single crystalline or grain-boundary free, using irradiation by a radiant energy beam such as a laser. To facilitate the transformation of the polysilicon film into a single crystal film, nucleation in the polysilicon film during recrystallization must be controlled so as to be initiated at a single point in a molten region of the polysilicon film. This can be achieved by producing a temperature distribution, in a region to be recrystallized, having a profile which affords the lowest temperature at the center of the region and higher and higher temperatures towards the periphery of the region.

There are many reports concerning methods of establishing such a temperature profile, including "Recrystallization of Si on amorphous substrate by doughnut-shaped cw Ar laser beam" by S. Kawamura et al., Applied Physics Letter 40 (5), p. 394, 1 March 1982. The doughnut-shaped laser beam, for example, produces a temperature profile having a lowest temperature at the position corresponding to the center of the beam. In United States patent application Serial No. 784,607, the present inventor discloses selective recrystallization of a polysilicon film, using an anti-reflective film having apertures formed therein at positions corresponding to regions ultimately to be single-crystalline in the polysilicon film. With the apertures, the anti-reflective film produces a desired temperature profile which affords a lowest temperature at the center of each region corresponding to the apertures. According to this method, any desired portion of a polysilicon film can be transformed into a single crystalline region of a desired size. The methods mentioned above can be categorized as direct-heating-type SOI technology.

In United States Patent 4,543,133, published September 24, 1985, and a report entitled "Single crystalline Si islands on an amorphous insulating layer recrystallized by an indirect laser heating technique for three-dimensional integrated circuits" on pp. 994-996 of Applied Physics Letter 44 (10), 15 May 1984, the present inventor discloses an SOI technology utilizing indirect heating of a polysilicon film. In the disclosure, islands of a polysilicon film and the surrounding substrate region are coated with an energy-absorbing cap layer. The energy-absorbing cap layer is irradiated with a radiant energy beam, such as an argon ion laser beam, to generate heat. Thus, the polysilicon film islands are melted by the heat transferred from the energy-absorbing cap layer by thermal conduction.

In such an indirect heating SOI technology, fluctuations in output power and intensity distribution of the laser beam are buffered by the energy-absorbing cap layer, and hence, stable and uniform heating can be attained. As a result, polysilicon islands can be recrystallized to be grain-boundary-free with improved reproducibility. Further, this indirect heating SOI technology allows the radiant energy beam to be freed from a need to correspond to the optical absorption characteristics of the to-be-recrystallized film such as polysilicon film. It requires only matching between the wavelength of the radiant energy beam, such as a laser beam, and the absorption spectrum of the energy-absorbing cap layer.

However, with the above-mentioned indirect heating SOI technology, the polysilicon film formed on an insulating layer is patterned to provide islands prior to the recrystallization. The size of each island must be large enough to include therein the source and drain regions together with the active region, i.e. channel region, of a transistor.

Generally, it becomes more difficult to establish the above-mentioned desired temperature profile over an island, as the size of the island becomes larger. This means that, in the previous indirect-heating SOI technology, the existence of recrystallized islands which in fact include a grain boundary has a relatively high probability. If, amongst a number of islands on a semiconductor chip, there is an (one) island having a grain boundary extending into the active region thereof (the active region of the device e.g. transistor to be formed in the island) the chip cannot be used for an integrated circuit and thus, the yield of integrated circuit chips based on the indirect-heating SOI technology is decreased.

As thus suggested, it is advantageous that a region to be recrystallized is as small as possible when a desired temperature profile is established therein. Accordingly, it is desirable to selectively recrystallize only a small region, corresponding to an active region of a device, e.g. the channel region of a transistor, and to leave other regions, corresponding to source and drain regions of the

transistor, in a polycrystalline state. However, the previous indirect-heating SOI technology is unable to selectively recrystallize only a region as small as a channel region in a polycrystalline island.

An embodiment of the present invention can provide a method for selectively transforming regions of a polycrystalline film of a conductive material into grain-boundary-free regions, in an indirect-heating SOI environment.

An embodiment of the present invention can provide a process which can improve the yield of integrated circuit devices fabricated based on SOI.

An embodiment of the present invention provides a process comprising steps of: forming a nonmonocrystalline film of a conductive material - (for example semiconductor material such as polysilicon) on an insulator; forming a thermal-conduction-controlling layer of silicon dioxide, for example, on the nonmonocrystalline film, the thermal-conduction-controlling layer having thickness selectively increased at each portion thereof corresponding to predefined regions of the nonmonocrystalline film; forming an energy-absorbing cap layer of polysilicon, for example, on the thermal-conduction-controlling layer; and irradiating the energy-absorbing cap layer with an energy beam of radiant energy sufficient to melt and transform the nonmonocrystalline film in the predefined regions to be grain-boundary free by the heat generated in the energy-absorbing cap layer.

Reference is made, by way of example, to the accompanying drawings, in which:-

Fig. 1 is a schematic sectional elevational view illustrating a recrystallization method according to previously proposed indirect-heating SOI technology;

Fig. 2 is a schematic sectional elevational view illustrating a process embodying the present invention; and

Figs. 3A-3G are respective schematic sectional elevational views illustrating steps in a process embodying the present invention.

Fig. 1 illustrates a recrystallization method according to a previously proposed indirect-heating SOI technology. In this SOI technology, an insulating film 52 is formed on a silicon substrate 51 and a polysilicon island 53 having a size corresponding to a semiconductor element, such as a transistor, to be fabricated therein is formed on the insulating film 52 through conventional vapour-phase growth and patterning techniques. A separating layer 54 is formed to cover the polysilicon island 53 and then a laser-absorbing layer 55 of polysilicon, for example, is formed on the insulating film 52, having thereon the polysilicon island 53, using a vapour-phase growth technique. The separating layer 54 is for preventing fusion of polysilicon island 53 and laser-absorbing layer 55.

The laser-absorbing layer 55 is irradiated with a radiant energy beam 56, such as an argon (Ar) ion laser beam, having an emission spectrum almost equal to the absorption spectrum of the polysilicon constituting the laser-absorption layer 55. Thus, heat is generated in the laser-absorbing layer 55 and the polysilicon island 53 is heated up, above its melting point, by heat transferred from the laser-absorbing layer 55 by thermal conduction. When the laser beam irradiation 56 is removed, the polysilicon island 53 recrystallizes.

However, grain boundaries sometimes occur in a few out of many thousands of islands, for example, formed on an integrated circuit chip, because each of the islands (such as the island 53) has a size as great as 20 × 60 square-microns in order to contain regions which will provide source and drain of a transistor, and hence, the temperature distribution formed therein is apt to deviate from a desired profile, as mentioned above.

Fig. 2 is a schematic sectional elevational view illustrating an embodiment of the present invention. Referring to Fig. 2, a conductive material film 2, a semiconductor film for example, is formed on an insulating film 1, and then a thermal-conduction-controlling layer (simply referred to as a TCC layer, hereinafter) 5 is formed on the conductive material film 2. The TCC layer 5 has a selectively-increased-thickness portion 4 corresponding to a region 3 at which a portion 8 of the conductive material film 2 is to be transformed so as to be grain-boundary free.

Then, an energy-absorbing cap layer 6 is formed on the TCC layer 5 and the energy-absorbing cap layer 6 is irradiated with a radiant energy beam 7. Thus the conductive material film 2 is melted by heat transferred from the energy-absorbing layer 6 and recrystallized.

The TCC layer 5 is usually composed of a material having a thermal conductivity relatively smaller than that of the energy-absorbing cap layer 6, and further, that of the conductive material layer 2.

Heat flowing from the energy-absorbing cap layer 6 to the conductive material film 2 is restricted by the TCC layer 5, particularly in the region 3. Thus, the temperature of the conductive material film 2 is lower in the region 3 than in surrounding regions. However, there is heat flow into the region 3 from surrounding regions, because of the temperature difference arising as described above. Hence, in the region 3, a temperature distribution is established which provides a lowest temperature at the center of the region, with temperature becoming higher and higher towards the periphery of the region.

During the recrystallization of the conductive material film 2, nucleation initiates only at the lowest temperature point in the region 3, and thus, the region 3 is transformed into a grain-boundary-free single-crystalline region. It will be clear that there is substantially no lower limit of the size of the region 3. Therefore, the region can be designed to be as small as the channel region of a transistor. This means that the probability of existence of a grain boundary in the recrystallized region 3 can be substantially decreased compared with that for a recrystallized island 53 provided as illustrated in Fig. 1 in accordance with the previously proposed method.

Figs. 3A-3G are respective schematic sectional elevational views illustrating steps in a process embodying the present invention. Like reference signs designate like or corresponding parts throughout.

Referring to Fig. 3A, a relatively thick lower insulating film 12, such as a silicon dioxide (SiO_2) film of 1-2 microns thickness, is formed on a silicon substrate 11 by thermally oxidizing the substrate, for example. Then, a polysilicon film 13 having a thickness of about 4000A is formed on the lower insulating film 12 using conventional low-pressure chemical vapour deposition (LP-CVD), for example.

Subsequently, another silicon dioxide (SiO_2) layer having a thickness of about 4000A is formed on the polysilicon film 13 using a conventional CVD method. The SiO_2 layer is patterned by a conventional reactive ion etching technique using a not-shown resist mask and etchant, CHF_3 gas, for example. Thus a SiO_2 layer pattern 14 is selectively formed to cover the polysilicon film 13 in region 3, in which the polysilicon film 13 is to be transformed to be grain-boundary free. The region 3 is defined as (destined to be) an active region, e.g. channel region of a transistor, and has an area of as little as 20 × 20 square-microns. The exposed surface 4 of the polysilicon film 13 around the SiO_2 layer pattern 14 is thermally oxidized so as to form another SiO_2 layer 15, of 300A thickness for example, as shown in Fig. 3B.

Referring to Fig. 3C, a silicon nitride (Si_3N_4) layer 16 having a thickness of 800A, for example, is formed on the SiO_2 layer pattern 14 and the SiO_2 layer 15 using a conventional CVD technique. The SiO_2 layer 15 has the role of preventing chemical reaction between the polysilicon film 13 and the Si_3N_4 layer 16 at high temperature, and the Si_3N_4 layer 16 has the role of promoting wetting of a laser absorbing layer of polysilicon, which is formed thereon later, to the substrate.

The SiO_2 pattern layer 14, SiO_2 layer 15 and Si_3N_4 layer 16 in all constitute a thermal-conduction-controlling layer 5, and the selectively-increased-thickness region 4 of the TCC layer 5 corresponds to the predefined region 3 in which the polysilicon film 13 is to be transformed to be grain-boundary free.

Following the above, an energy-absorbing layer 17 of polysilicon, for example, of about 7000A thickness is formed on the substrate having the TCC layer 5, using a conventional LP-CVD technique. Further, as an anti-reflective film 18 for a laser beam, a Si_3N_4 film 18a and a SiO_2 film 18b, each having a thickness of about 300A, are successively formed on the polysilicon energy-absorbing layer 17, as shown in Fig. 3D.

Referring to Fig. 3E, a radiant energy beam 7 is scanned over the polysilicon energy-absorbing layer 17 with preliminary heating applied to the substrate, and thus, the energy-absorbing layer 17 is heated up to a high temperature of about 1500-1600° C. An Ar-ion laser which outputs a beam of 500 nanometer wavelength, for example, is desirably used as the source of the radiant energy beam 7, since silicon reveals strong absorption at this wavelength. The laser beam is tuned so as to provide a Gaussian type intensity distribution in the spot of irradiation provided by the beam. Further, the size of the spot must be large enough to encompass the predefined region of the polysilicon film 13 so that the polysilicon film 13 in the predefined region (20 × 20 square-microns) is melted by a single scan of the laser beam 7. Exemplary conditions for the laser beam irradiation are summarized as follows:-

Beam spot size: 100 microns in diameter
Intensity of beam: 13-15 Watts
Scanning speed: 2.5 cm/sec
Substrate temperature: 450°C.

With laser beam irradiation under the above conditions, for example, the polysilicon film 13 is melted by the heat transferred from the energy-absorbing layer 17 by conduction via the TCC layer 5. During the laser beam irradiation, the energy-absorbing layer 17 of polysilicon is also melted. In the predefined region, the heat flowing into the polysilicon film 13 under the SiO_2 layer pattern 14, i.e. the large-thickness portion 4, of the TCC layer 5 is less at the central portion as compared with that at the peripheral portion, as mentioned before. Thus, a temperature distribution is established in the polysilicon film 13 in the predefined region having a profile providing the lowest temperature at the center with temperature becoming higher towards the periphery. Accordingly, recrystallization of the polysilicon film 13

proceeds to spread from the lowest temperature central portion to the peripheral portion, and thus, a grain boundary-free region 213 is formed in the recrystallized silicon film 113.

Microscopic observation reveals that grain boundaries existing in the recrystallized silicon film 113 extend so as to shun or avoid the region 213, or are stopped at the border of the region 213, and no grain boundary is found in any predefined region 213.

Following the above, the Si_3N_4 film 18a and SiO_2 film 18b, constituting an anti-reflective layer, are removed using respective conventional etchants; a phosphoric-acid-type solution for the Si_3N_4 film 18a and a fluoric-acid-type solution for the SiO_2 film 18b, for example. Subsequently, the polysilicon energy-absorbing layer 17 is removed by using a conventional etchant such as a mixture of fluoric acid and nitric acid solutions, and then, the Si_3N_4 layer 16 and SiO_2 layers 15 and 14 are removed by using respective conventional etchants; a phosphoric acid solution for the Si_3N_4 layer 16 and a fluoric acid solution for the SiO_2 layers 15 and 14. Thus, the TCC layer 5 is removed and the recrystallized silicon film 113 including the predefined region 213 which has been selectively transformed to be grain-boundary-free is exposed as shown in Fig. 3F.

Referring to Fig. 3G, the recrystallized silicon film 113 is patterned by a conventional RIE (reactive ion etching) technique incorporating a not-shown resist mask and an etchant such as a gas mixture of CF_4 + O2, for example, and an island 19 of the recrystallized silicon film 113 including the grain-boundary-free region 213 is formed on the SiO_2 lower insulating layer 12. Thus an SOI substrate having a desired number of silicon islands each including a grain-boundary-free region such as the region 213 is completed.

Following the above, a semiconductor circuit element such as a transistor is formed in the silicon island 19, wherein the active region of the element, such as the channel region of a transistor, is allocated in the grain-boundary-free region 213 and source and drain regions of the transistor are fabricated in the recrystallized silicon region 113 around the grain-boundary-free region 213. Thus, an integrated circuit having an SOI structure is provided.

According to this embodiment of the present invention, the recrystallized silicon island 19 has a size of 20 $\times$ 60 square-microns, for example, the same as that of the silicon island 53 shown in Fig. 1 in relation to the previous proposal. However, only a smaller region, such as the active region of a transistor, formed in the island is selectively transformed to be grain-boundary-free. Therefore, the probability of existence of a grain boundary in the active region is substantially decreased, and hence, the yield of SOI ICs can be increased. Further, employing embodiments of the present invention, using indirect-heating SOI technology, the shape of island need not be simple (e.g. rectangular) but can be complicated, for example with the structure of letters C, E, H and so forth, wherein a desired number of active regions can be formed in the structure.

The above embodiment of the present invention relates to the provision of an SOI structure for a semiconductor integrated circuit. However, a recrystallization method embodying the present invention can be applied to a metallized layer of an integrated circuit. That is, a wiring layer such as one formed from amorphous aluminum, fabricated by a vacuum deposition or sputtering technique, for example, can be selectively transformed into a grain-boundary-free aluminum layer. Such a grain-boundary-free wiring layer can eliminate a type of disconnection which occurs in wiring lines for large current load due to existence of grain boundaries therein.

It is to be understood that various modifications of the described embodiments of the present invention can be effected. For example, the SiO_2 film 15 and Si_3N_4 film 16 and the anti-reflective layer 18 shown in Fig. 3D are not essential. Further, the energy-absorbing layer 17 in Fig. 3D, for example, need not be of polysilicon: that layer may be of other materials, provided matching of the wavelengths is established between the emission spectra of the laser beam and the absorption spectra of the energy-absorbing layer, wherein the other materials may have a higher melting point than that of the film to be recrystallized.

An embodiment of the present invention provides a process allowing so-called indirect-heating SOI methodology to selectively transform predefined regions of a semiconductor film formed on an insulating substrate into grain-boundary-free regions. In an indirect-heating SOI, a semiconductor film which is recrystallized to be grain-boundary-free is heated above its melting point by the heat generated in an energy-absorbing layer formed thereon. In an embodiment of the present invention, a layer having a relatively smaller thermal conductivity, such as a SiO_2 layer, is provided between the semiconductor film to be recrystallized and the energy-absorbing layer, both having larger thermal conductivities. The smaller-thermal-conductivity layer, functioning as a thermal-resistance, has selectively increased thickness at the portions thereof corresponding to the predefined regions to be transformed to be grain-boundary-free in the semiconductor film. In each of the predefined regions, a desired temperature distribution profile, that is, the lowest temperature at the center of the

region and temperature becoming higher towards the periphery of the region, is established, when the energy-absorbing layer is irradiated with a beam of radiant energy sufficient to melt the semiconductor film. Thus, the semiconductor film can be recrystallized to be grain-boundary-free single crystalline in each predefined region.

Claims

1. A process of forming a semiconductor device, comprising steps of:
forming a nonmonocrystalline film of a semiconductor material on an insulator, the nonmonocrystalline film including a predefined region in which the nonmonocrystalline film is to be recrystallized to be grain-boundary-free, using heat supplied thereto by thermal conduction;
forming a thermal-conduction-controlling layer over the nonmonocrystalline film, said thermal-conduction-controlling layer being for providing selective thermal resistances to the thermal conduction of heat to the nonmonocrystalline film and having a selectively increased thickness at the portion thereof corresponding to said predefined region of the nonmonocrystalline film;
forming an energy-absorbing cap layer for absorbing radiant energy and generating heat enough to melt the nonmonocrystalline film on said thermal-conduction-controlling layer; and
irradiating the energy-absorbing cap layer with an energy beam of radiant energy sufficient to melt and to transform the nonmonocrystalline film in said predefined region to be grain-boundary-free by the heat generated in the energy-absorbing cap layer.

2. A process according to claim 1, wherein the thermal conductivity of the thermal-conduction-controlling layer is smaller than that of the energy-absorbing cap layer.

3. A process as claimed in claim 1 or 2, wherein the insulator is a film formed on a semiconductor substrate.

4. A process as claimed in claim 3, wherein the substrate is of silicon and the insulator is a silicon oxide film formed by oxidizing the silicon substrate.

5. A process as claimed in any preceding claim, further comprising a step of forming an anti-reflective layer on the energy-absorbing cap layer, said anti-reflective layer being for reducing reflection of the radiant energy beam incident on the surface of the energy-absorbing cap layer.

6. A process as claimed in any preceding claim, wherein the semiconductor material is polycrystalline silicon, the energy-absorbing cap layer is of polycrystalline silicon, and the energy beam is an argon ion laser beam.

7. A process as claimed in any preceding claim, wherein said thermal-conduction-controlling layer is a silicon dioxide layer.

8. A process as claimed in any preceding claim, further comprising a step of forming a wetting layer between the energy-absorbing cap layer and the thermal-conduction-controlling layer.

9. A process as claimed in claim 8, wherein the wetting layer is formed from silicon nitride.

10. A method of recrystallizing a region of a nonmonocrystalline conductive layer, comprising:-
forming a thermal-conduction-controlling layer above the nonmonocrystalline layer (the latter being, for example, of polysilicon or amorphous aluminum), the thermal-conduction-controlling layer having a portion of increased thickness above and corresponding to the said region of the nonmonocrystalline conductive layer, so as to provide greater thermal resistance at that portion that is provided by surrounding portions;
forming an energy-absorbing cap layer above the thermal-conduction-controlling layer; and
irradiating the energy absorbing cap layer with an energy beam;
the energy-absorbing cap layer absorbing energy from the beam and, as a result, heating up, the thermal-conduction-controlling layer conducting heat from the cap layer to the nonmonocrystalline layer in a selective fashion owing to the presence of the increased-thickness portion, such that material of the nonmonocrystalline layer in the said region is melted and provided with a temperature distribution such that it recrystallizes, on cooling, in a grain-boundary-free condition.

FIG. 1

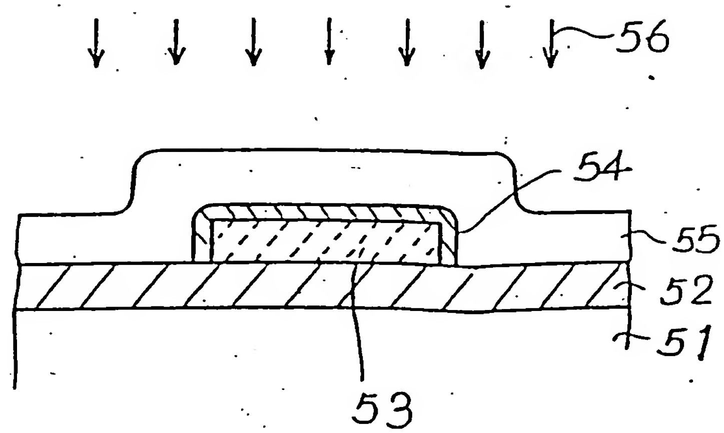

FIG. 2

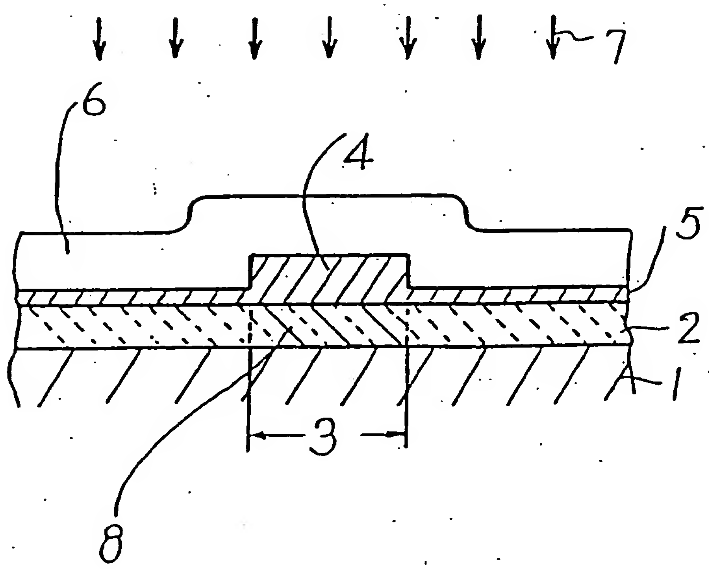

FIG. 3A

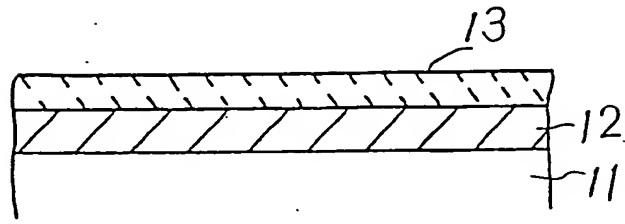

FIG. 3B

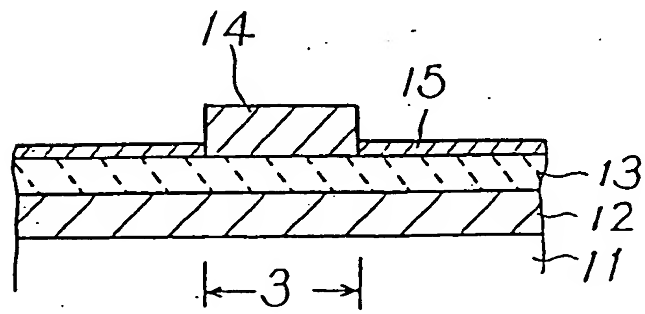

FIG. 3C

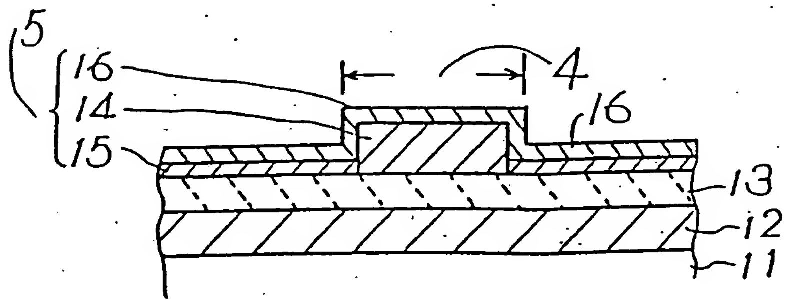

FIG. 3D

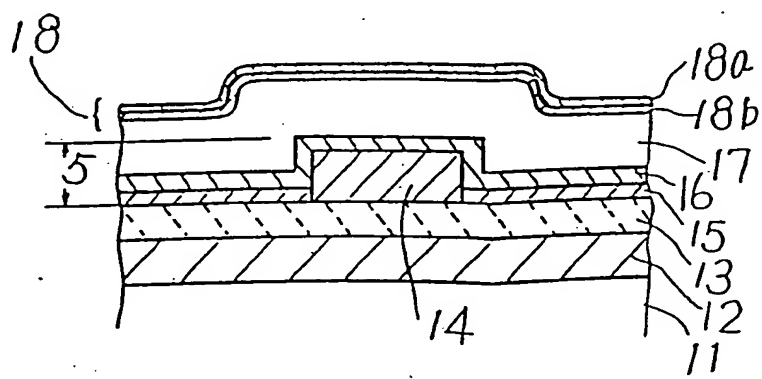

FIG. 3E

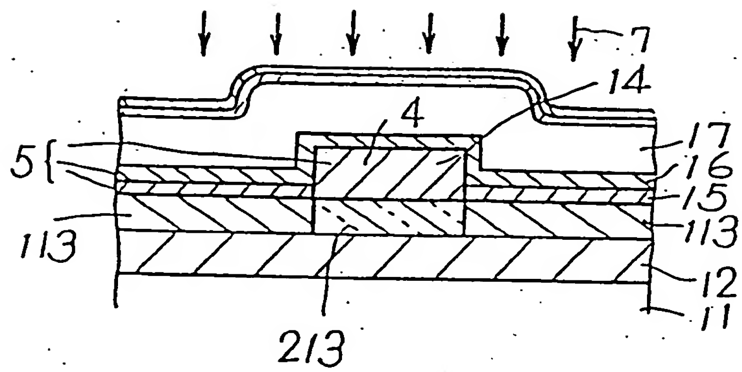

FIG. 3F

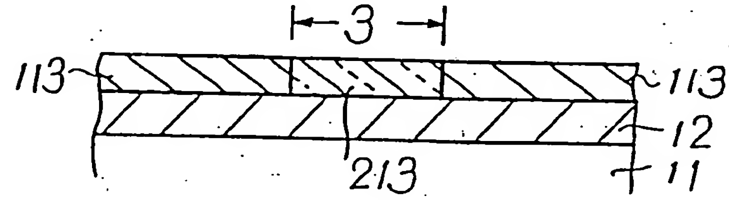

FIG. 3G